

Environmental Research and Technology Development

Preserving the environment is an ongoing challenge facing the U.S. As one of the nation's largest environmental research and development groups, we are assessing the biological and health effects of exposure to various substances of concern. We are also developing new equipment and processes to minimize or treat waste and maintain a clean environment.

In 1994, most of the Laboratory's environmental research, development, and demonstration projects were consolidated into one organization, the Environmental Programs Directorate. Our activities extend from basic research in geological, atmospheric, and environmental phenomena to applied research and pilot-scale testing of technologies for environmental remediation and waste management.

Our projects draw on expertise from across the Laboratory in areas such as microbiology, laser technology, engineering, computer science, chemistry, and nuclear physics. The products of our work include policy analysis, model and technology development across many disciplines, environmental remediation technologies, hazards mitigation and emergency assistance, and basic research.

Geophysical and Environmental Research

The following sections highlight our recent work in geophysical and environmental research.

Regional Atmospheric Sciences

We investigate atmospheric processes on local to regional scales for applications of regional and national importance. One focus is on applying models to predict the dispersion and deposition of hazardous emissions in the atmosphere. Another is to develop new models to refine our understanding of important atmospheric phenomena, including cloud formation and dissipation, precipitation and water-basin loading, turbulence and energy dissipation, stratified flows, and flows over complex terrain. We are also developing infrared-laser technology for remote sensing of the atmosphere.

Our evolving technical capabilities converge in the Atmospheric Release Advisory Capability (ARAC). ARAC operates as a national center for the DOE's Emergency Response Program and several DOD programs, and for other federal and state agencies. ARAC provides state-of-the-art, real-time, model-derived assessments of the health and environmental impacts of atmospheric releases of radionuclides and other hazardous materials. Assessments, which are available worldwide and 24 hours a day, incorporate detailed terrain effects, continuously updated three-dimensional meteorological data, and nationally approved health impact factors. In 1994, ARAC began assessments related to nonproliferation issues. Our new Atmospheric Emergency Response Facility, scheduled for completion in early 1996, will house the national ARAC operations and training center.

Global Climate Research

To improve our understanding of potential climate changes that could occur as a result of human activities or natural events, we develop, test, and apply global climate models. We conduct research on the chemistry and biogeochemical cycles of trace species and aerosols in the troposphere and stratosphere. Our models describe the chemistry and physics of interactions from the

Artist's rendering of the new Atmospheric Emergency Response Facility at LLNL. This building will house the national ARAC operations and training center. Construction began in August 1994, and we expect to move into the facility in January 1996.



micro scale to the global scale. Other research topics include the physics of clouds and their radiative properties, climate variability, and studies of heat, momentum, and water budgets. Our ultimate objective is to develop a coupled system model that represents the full set of coupled physical, chemical, and biological processes that govern the behavior of the climate system.

We have carried out the first climate simulations that include the effects of both increasing greenhouse gases and increasing aerosols. Aerosols are the minute solid or liquid particles produced both naturally and by human activities, such as burning fossil fuels. For several decades, researchers have recognized that aerosols could affect the amount of solar radiation reaching Earth's surface. Aerosols reflect some incident sunlight back to space (the direct effect), and they can also serve as nuclei for the condensation of water vapor (the indirect effect), causing an increase in the global cloud cover. Both effects cool the atmosphere and, globally averaged, tend to offset warming caused by increases in greenhouse gases, such as carbon dioxide. Our study considered the combined effects of increasing greenhouse gases and the direct aerosol effect, taking into account the nonuniform geographic distribution of aerosol sources. The results show a complicated pattern of climate change, with cooling in some regions and warming in others. Thus, the pattern of climate change caused by human activities could be quite different from that predicted by most current global climate models, which do not account for aerosols.

The Atmospheric Model Intercomparison Project, which is led by our Program for Climate Model Diagnosis and Intercomparison, is being carried out in cooperation with the United Nations' World Climate Research Programme. This project is the largest internationally coordinated test of atmospheric models ever undertaken. In all, 30 different models are being used to simulate the atmosphere's behavior from 1979 to 1988. We are assembling an archive of model results and observed data from this project for use by the climate-modeling and diagnostic communities.

Health and Ecological Assessment

Our research in this area includes the development of methods and instruments to detect and quantify environmental pollutants from DOE and related operations. This work ranges from

environmental characterization and models to predict the transport of contaminants through all environmental media to the exposure of people. We are developing biological dosimetry capabilities for radionuclides and chemicals, evaluating ecological responses and restoration methods, and developing expertise in dose and risk assessment. This research is the basis for field assessments of contaminated sites, such as those at LLNL, the Nevada Test Site, and the Marshall Islands. Our Risk Sciences Center serves as a focal point for risk-related research at the Laboratory and as a bridge to researchers at UC campuses.

We are developing an innovative method for estimating human exposure to the radioactive iodine released at Chernobyl to correlate this exposure with thyroid cancer. Iodine concentrates

Highlights for 1994

- Broke ground for a new facility that will house the Regional Atmospheric Sciences Division and ARAC, which currently occupy several facilities.
- Received DOE authorization to proceed with the next phase of planning and construction of the Mixed Waste Management Facility at LLNL. This pilot-scale facility will allow us to test new treatment processes for the destruction and immobilization of mixed waste.
- Conducted the first field study of the biofilter concept at the Kennedy Space Center in Florida; these filters can degrade TCE in groundwater.
- Demonstrated the Dynamic Underground Stripping technology for the in-situ cleanup of fuel hydrocarbons in the subsurface.
- Conducted the first integrated study of the effects of atmospheric aerosols on global climate, showing that aerosols must be considered in any analysis of global warming caused by an enhanced greenhouse effect.
- Continued working with Caltrans and the California State Seismic Safety Commission to assist the state in its seismic assessments of highway and bridge structures.
- Worked with California state meteorologists to explore improved weather prediction methods that, in the future, could assist the state in managing its water resources.
- Constructed the 1500-liter bioreactor facility, which will allow LLNL and other DOE and UC scientists to grow large quantities of bacteria for use in large-scale research, industrial, and environmental applications.

Our new climate simulation of the direct aerosol effect and the effect of increasing greenhouse gases takes into account the nonuniform geographic distribution of aerosol sources. In response to summertime increases in aerosols and CO₂, the simulation predicts areas of cooling and other areas of warming.

in the thyroid, and exposure to radioactive ^{131}I is known to cause thyroid cancer. The 8-day half-life of ^{131}I , however, causes it to decay to undetectable levels within a few months, making it impossible to measure how much was deposited following the accident.

The Chernobyl accident also released another isotope of iodine, ^{129}I , in a known proportion to ^{131}I . Both species have identical chemical behavior and should have been released and deposited in the same way following the accident. Because of its 15.7-million-year half-life, essentially all the ^{129}I that was released is still present. This means that we can use the current abundances of ^{129}I to calculate the amount of ^{131}I that was deposited in an area.

Because concentrations of ^{129}I are extremely low, they cannot be measured using conventional counting techniques. We can, however, use the capabilities of the LLNL Center for Accelerator Mass Spectrometry to make the necessary measurements. Working with scientists from Belarus, Ukraine, and Russia, we collected more than 200 soil samples from 10 settlements in Belarus that are part of an ongoing thyroid cancer study; the aim of this study is to measure the health impact of the Chernobyl accident on children. Our preliminary measurements indicate that we can reconstruct ^{131}I exposures from Chernobyl. If successful, the same methodology could be used to reconstruct iodine doses resulting from other atmospheric releases.

Earth Sciences

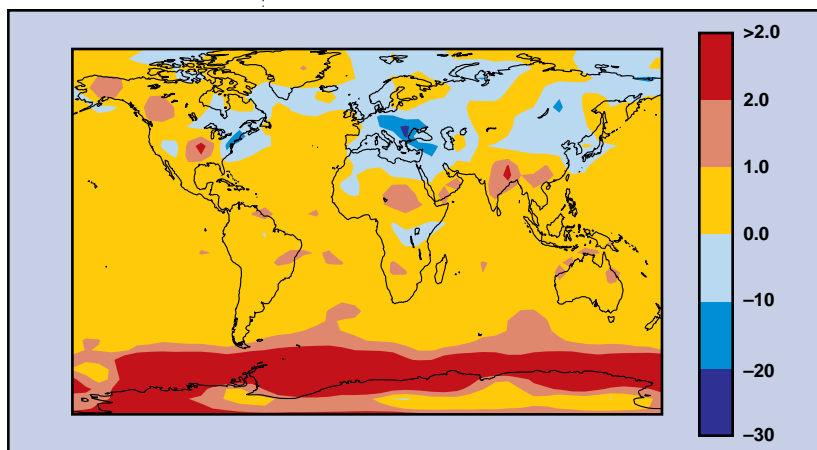
We are developing innovative technologies to characterize and remediate subsurface contamination and are researching advanced methods for defining and quantifying earthquake hazards. Our seismology group, with its long history of treaty verification research, is examining issues related to nonproliferation. We support the Weapons Program by studying the properties of nuclear materials at extreme pressures and temperatures. We are also helping to resolve issues related to the geochemistry, hydrology, thermomechanical response, and radionuclide transport in the environment that would surround waste packages at the candidate high-level nuclear waste repository at Yucca Mountain, Nevada. We are responsible for understanding the long-term, in-repository behavior of high-level nuclear waste.

Other energy-related research includes geophysical and seismological studies of geothermal fields, studies of the chemical kinetics of petroleum formation, and seismic, geochemical, and geophysical studies related to oil and gas exploration and production. We have an extensive basic research program in areas ranging from the tectonics of the earth, to underground imaging technologies, to studies of the physical, chemical, and transport properties of geological and other materials at high temperatures and pressures. Our basic research program continues to be enriched by the Center for Geosciences of the Institute for Geophysics and Planetary Physics, which promotes collaborative research with scientists at UC campuses.

Center for Accelerator Mass Spectrometry

The Center for Accelerator Mass Spectrometry is becoming the world's most versatile and productive facility of its kind. We now routinely measure the low-abundance isotopes ^3H , ^7Be , ^{10}Be , ^{14}C , ^{26}Al , ^{36}Cl , ^{41}Ca , and ^{129}I at levels of 1 part in 10^{12} to 10^{15} . No other facility can measure more than two or three of these tracers or chronometers. Furthermore, we can switch among these isotopes relatively easily and quickly.

We ran approximately 13,000 research samples last year for investigators at LLNL and at many other places, including the DOE, University of California (UC), and other universities, federal agencies, and various institutes and corporations. Our research

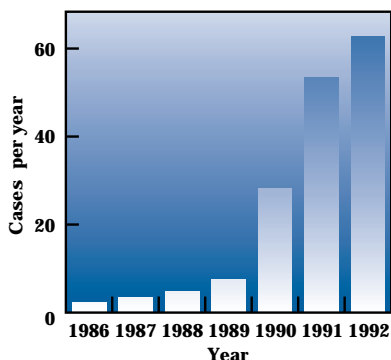


programs are diverse, including archaeology, art history, dosimetry of carcinogens and mutagens, oceanic and atmospheric chemistry, paleoclimatology, forensic reconstruction of Hiroshima, dosimetry at Nagasaki and Chernobyl, and identification of signatures of nuclear fuel reprocessing. New applications with joint UC and DOE sponsorship include investigations in nutritional science and dermatology, the calcium chemistry of heart cells during cardiac stress, the hydrological record of Northern California watersheds, biogeochemical processes in the carbon cycle, and new techniques for archaeological dating. We expect the number of participating researchers, now totaling nearly 380, to increase as our capabilities grow.

Geologic and Atmospheric Hazards Program

LLNL has been assessing the hazards associated with natural phenomena since the 1970s. The DOE is concerned about possible damage to its facilities from such natural hazards as earthquakes, storms, floods, lightning, volcanic eruptions, and extreme heat or cold. Because of our comprehensive capabilities, LLNL has become the hazards mitigation center for the DOE in the area of natural phenomena.

Recently, we began to develop a new method to evaluate the effects on structures of large earthquakes originating from specific faults. The aim is to define more realistic engineering standards. Our approach integrates three disciplines: seismology and



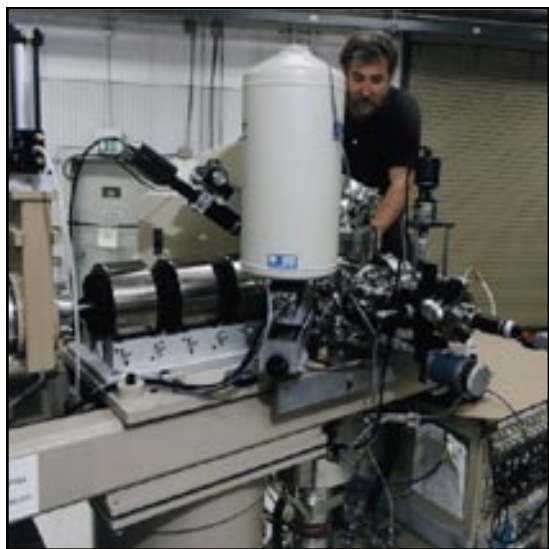
About 25% of Belarus is radioactively contaminated. The incidence of thyroid cancer in children living in Belarus has been steadily increasing since the Chernobyl accident in 1986 and is now at alarming levels. We are reconstructing thyroid doses to children from radioiodine using the grass-cow-milk pathway.

geomechanics provide an estimate of expected ground motion, whereas structural dynamics provides the dynamic response of the structures themselves. The calculations use the sophisticated nonlinear, three-dimensional, finite-element codes developed at LLNL. With Caltrans, we have applied our methodology to two bridges in California: the Painter Street overcrossing of Highway 101 in Rio Dell, and the Dumbarton Bridge spanning San Francisco Bay. In 1994, the state of California asked us to assess a highway interchange in the Bay Area so that they can compare the predictions with those of a conventional analysis. (See *E&TR*, Sept.–Oct. 1993.)

We are also developing a system that could warn of the impending arrival of a damaging seismic wave from an earthquake. The system relies on an array of seismographs deployed throughout a seismically active area and broadcasts a radio warning signal if the magnitude is of concern. Because seismic waves propagate at very slow speeds relative to radio signals, locations several tens of kilometers from the epicenter of an earthquake will receive a warning signal 10 to 25 seconds before an earthquake arrives. Advance warning could be used to shut down hazardous operations, start emergency generators, open the garage doors of fire stations, and so forth. A similar system could also be used to warn of large aftershocks, making it possible to reduce the danger to which emergency workers are exposed.

Environmental Technologies Program

Many ideas for new environmental technologies come from basic research; others result



The Center for Accelerator Mass Spectrometry can now routinely switch, daily or at shorter intervals, among eight low-abundance isotopes that serve as tracers or chronometers. One of our collaborators, Dan Morse from Sandia National Laboratories, is making adjustments to the new microprobe beamline.

from new applications of existing technologies. One of the strengths of a multiprogram laboratory such as LLNL is the cross-fertilization of ideas from people working on different projects. The role of our applied technology programs is to turn ideas into working systems and to demonstrate their effectiveness. Below are highlights of some of our recent efforts.

Optical Fiber Sensors

To measure the concentration of contaminants in groundwater today, investigators must withdraw water from a well, transport a sample to a laboratory, and make measurements with analytical instruments. Our approach involves optical fibers that are pushed into the ground using a device called a cone penetrometer. The aboveground end of the fiber is connected to a briefcase-size instrument that quickly measures and displays the abundance of contaminants. Optical fiber sensors emplaced in wells continuously sense the concentrations of groundwater contaminants and are cheaper and much more convenient than conventional sampling techniques.

Dynamic Underground Stripping

Developed jointly by UC Berkeley and LLNL, this technique combines steam and electrical currents

to heat soils and enhance contaminant recovery. Collection wells bring the contaminants to the surface, where they are treated and disposed. An underground imaging method, called electrical resistance tomography, monitors and controls the process. In 1994, we demonstrated the dynamic stripping technology to clean up gasoline that leaked many years ago from several underground tanks at LLNL. We removed more than 29,000 liters of gasoline from 600,000 m³ of soil at depths of 25 to 45 m. Our cleanup took only a few months compared to the decades estimated for traditional processes. We are exploring this technique to clean up chlorinated solvents, such as trichloroethylene (TCE) and perchloroethane (PCE), and we are using tailored steam chemistry to enhance the removal of toxic or radioactive metals from soils.

Microbial Filter

To prevent the spread of groundwater contamination, we have been developing a concept involving the injection of bacteria in a resting state to form a subsurface barrier of microbes. We previously tested the concept in the laboratory using a strain of naturally occurring aerobic bacteria that can co-metabolize toxic chlorinated hydrocarbons, such as TCE. Last year, we conducted the first in-situ test at a site at the Kennedy Space Center in Florida. The purpose of the test was not to remediate but, rather, to determine the capacity of the bacteria to degrade contaminants in an actual subsurface environment. We monitored groundwater pumped through several columns that were inoculated with our strain of bacteria. Results from two test wells showed that the bacteria retain their ability to degrade chlorinated and fluorinated hydrocarbons under the conditions present at that site.

We constructed a large-scale bioreactor facility that was completed in late 1994. The centerpiece of the facility is a 1500-liter bioreactor for growing the large quantities of bacteria needed to conduct full-scale field tests. The facility also includes microbiology laboratories to identify and isolate bacterial strains, and smaller bioreactors for laboratory experiments. These facilities are unique in the DOE complex and the UC system, and we expect many researchers to use them for other applications.

Teams of LLNL scientists go into the field after major earthquakes to study how and why structures are damaged. Our investigations included damage done by the January 1994 earthquake in Northridge, CA.



Waste Treatment and Disposal Technologies

Maintaining a clean environment demands new techniques for treating and disposing of hazardous waste. Of particular concern are mixed wastes, which contain both radioactive and toxic materials—typically organic chemicals. Such materials are generated by medical research, hospitals, industry, and the military, but there are few accepted ways to process such wastes and make them suitable for disposal. Incineration, for example, has met with considerable public opposition. We have developed the following alternatives to incineration, each optimized for a particular class of waste.

Molten Salt Destruction. Developed with Oak Ridge National Laboratory and the Energy Technology Engineering Center, our molten salt process simultaneously destroys organic materials and traps inorganic and radioactive constituents in the salt. This process is promising for treating medical mixed waste that cannot be incinerated and hazardous wastes from industry and the military.

Mediated Electrochemical Oxidation. This aqueous, room-temperature process generates silver and cobalt ions in an electrochemical cell. The ions are extremely effective at decomposing toxic organic compounds into carbon dioxide gas and water vapor that can be safely vented into the atmosphere after treatment.

Photolytic Destruction. Photolytic destruction combines ultraviolet (UV) light and hydrogen peroxide (H_2O_2) to destroy trace organic compounds in a wastewater stream. We have been working to develop high-efficiency, short-wavelength UV lamps that greatly reduce the electrical power demand and improve the economics of the process.

Measurement and Characterization. We are developing smart systems for recognizing and sorting waste, tomographic techniques for noninvasive measurements of the contents of waste drums, and advanced radiation detector systems for verifying the uranium and plutonium concentrations in wastes.

Mixed Waste Management Facility

The Mixed Waste Management Facility at LLNL, slated to be completed in 1997, is a key element in the deployment of effective and environmentally acceptable treatment processes as



LLNL scientists recently conducted a feasibility test of the microbial filter concept at the Kennedy Space Center in Florida. This work revealed that aerobic bacteria can degrade chlorinated and fluorinated hydrocarbons under the conditions present at the site.

alternatives to incineration for low-level organic mixed waste. Our pilot-scale demonstration facility will provide a bridge between bench-scale demonstrated technologies and full-scale deployment and operation of facilities anticipated in response to the Federal Facilities Compliance Act. The facility will address development, engineering, process integration, and activation issues and allow for public participation. For initial operations in the facility, molten salt oxidation and mediated electrochemical oxidation have been selected as the primary process technologies. The process support systems will provide all essential support functions required of a fully integrated plant.

Summary

Our goal is to better understand geological, atmospheric, and environmental phenomena as well as to contribute substantially to the nationwide effort to clean up the environment and come up with better ways to design and manufacture effective products. Many of our new technologies are making their way into the commercial sector, and many more are on the drawing boards. The continued dedication of researchers from institutions like LLNL is helping to make the U.S. environmentally clean and economically competitive.

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